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Restoration of Central-European mountain Norway spruce forest 15 years after natural and anthropogenic disturbance

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ABSTRACT

Storm events resulting in windthrows, bark beetle (*Ips typographus*) outbreaks and subsequent forestry operations are the main disturbance agents in European mountain Norway spruce (*Picea abies*) forests. In the 1990s, a bark beetle outbreak resulted in a large-scale dieback of semi-natural mountain spruce forests in the Šumava National Park, Czech Republic. Two applied management measures enabled long-term monitoring of the effect of natural and anthropogenic disturbance on forest recovery: core zones were left without intervention, and surrounding zones were clear-cut, trees removed, and cleared areas replanted. Research plots were established in three disturbance types: climatically conditioned spruce forest with dead canopy, without intervention (1), with intervention (2), and waterlogged spruce forest partly resistant to bark beetle disturbance without intervention (3). The amount and vertical structure of tree regeneration and vegetation changes have been studied since the beginning of the disturbance in 1997.

The main question of the study was whether tree regeneration and herb-layer vegetation differed between naturally developing disturbed forests and clearcuts 15 years after the disturbance. The species composition of regeneration in all disturbance types consisted mainly of spruce, with accompanying rowan. The total numbers after 15 years since the beginning of the disturbance did not differ significantly among the studied disturbance types, and were sufficient to replace the previous canopy. However, in clearcuts, these numbers were achieved by artificial reforestation, which was applied after initial destruction of natural regeneration due to salvage operations, whereas advance natural regeneration grew successfully under the protection of unmanaged dead canopy. There was a more unified height structure of spruce regeneration in the clearcuts, with significantly higher numbers of saplings taller than 2 m compared to unmanaged forests. Due to a less harsh change in site conditions, typical herb species flourished in the non-intervention zones in comparison to the clearcuts. The impact of post-disturbance interventions on herb-layer vegetation was still obvious 15 years after the event. Therefore, a non-interventional approach is recommended as the best for restoration of mountain Norway spruce forests affected by large-scale natural disturbances.

1. Introduction

Natural disturbances represent an important part of mountain Norway spruce (*Picea abies*) forest dynamics (Attiwil, 1994; Svoboda et al., 2012). They determine the proportions of stands in various stages of development at the landscape level (Frelich, 2002). To better understand recently occurring disturbances, several studies from Central Europe reconstructed the disturbance history to shed more light on the range of historical variability for mountain Norway spruce (*P. abies*) forest ecosystems in the region (Brůna et al., 2013; Čada et al., 2013; Svoboda et al., 2012). They revealed that this range comprises a continuum from small-scale gap dynamics to large-scale, high-severity disturbances occurring at various temporal and spatial scales.

Wind and bark beetle outbreaks are the main disturbance agents occurring in European mountain Norway spruce forests. Large-scale bark beetle outbreaks initiated by strong wind occurred recently along the German–Czech border in the Bayerischer Wald (Heurich et al., 2001; Lausch et al., 2011) and Šumava Mts. (Jonášová and Prach, 2004), along the Slovak-Polish border in the Tatra Mts. (Grodzki et al., 2006), and in the Swiss Alps (Kupferschmid and Bugmann, 2005). When such large-scale

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disturbances occur, however, there is usually a need to prevent their spreading (Ilisson et al., 2007; Lindenmayer et al., 2008). Traditionally, the disturbed stands were logged with the aim to salvage at least the timber and to prevent further progress of the bark beetle outbreak, with the tendencies to use the same management even in protected areas. As a result, there is a general lack of knowledge of natural regeneration processes after disturbances of mountain spruce forests in Central Europe since it is rare that forests are left to spontaneous development after the disturbances (Heurich, 2009; Schelhaas et al., 2003).

Nowadays, there is a strong need for restoration of European forests to more natural conditions (Halme et al., 2013; Ranius et al., 2014). The requirement for salvage logging in protected areas, however, contradicts the conservation objective to enhance forest biodiversity and natural processes (Bässler et al., 2012). The first use of non-interventionist management in Central-Europe was in the Bayerischer Wald NP after large-scale windthrows in 1983 and 1984 and subsequent bark beetle outbreaks (Heurich et al., 2001). Large areas of disturbed stands were left without any management measures and spontaneous development of the forest has been studied (Fischer et al., 2002; Heurich, 2009; Jehl, 2001). Müller et al. (2010, 2008) recently clarified the role of bark beetle as a key-stone species for mountain spruce forests. Since the late 1990s, surveys of regeneration processes have come also from the Czech side (Jonášová and Matějková, 2007; Jonášová and Prach, 2004) and recently other studies dealing with regeneration processes have been conducted (Bače et al., 2012; Svoboda and Pouska, 2008; Svoboda et al., 2010).

Here, results are presented of a long-term monitoring study of forest recovery after a bark beetle outbreak and subsequent sanitation felling and salvage logging operations in spruce forests in the central part of the Šumava NP beginning in the second half of the 1990s. The objectives of the study were, first, to compare both naturally developing disturbed forest stands and clearcut stands during 15 years of post-disturbance development and, secondly, to outline the spontaneous development of both climatically and edaphically conditioned spruce forests. Studying these aspects together make the study rather unique in the context of Central Europe. The questions were: (1) Are the differences between naturally developing forests and clearcuts noticeable 15 years after the onset of disturbances? (2) How does tree regeneration evolve through time? (3) How does species composition of the herb-layer vegetation differ or change over time in forests with or without interventions?

2. Methods

2.1. Study area

The study area was located in the central part of the Šumava Mts. (the Bohemian Forest), in the SW of the Czech Republic (48°56′–48°59′N, 13°25′–13°29′E) at altitudes ranging from 1175 to 1280 m.a.s.l. (Fig. 1). Since 1991, the area has formed the central part of the Šumava NP, extending along the border with the Bayerischer Wald (the Bavarian Forest) NP, Germany. The bedrock is composed of metamorphic migmatite, partly of igneous biotitic granite up to granodiorite (Czech Geological Survey, 2012). Podzols are the prevailing soil group, accompanied by histosols on waterlogged shallow slopes and in depressions, and gleysols on non-calciferous deluviofluvial and fluvial sediments (Neuhäuslová, 2001a). The area has a boreal climate (climatic class Dfc) with mean annual temperature about 4 °C and mean annual precipitation about 1500 mm (Tolasz et al., 2007).

The study area is characterized by forest complexes of mountain Norway spruce forests (of alliance *Piceion excelsae* Pawłovski in Pawłovski, Sokołowski and Wallish 1928), the formation of which was induced both climatically (climatically conditioned Norway spruce forests) and edaphically (waterlogged Norway spruce forests) (Neuhäuslová, 2001a). The climatically conditioned spruce forests occur over approximately 1200 m.a.s.l. Norway spruce dominates in the tree layer with possible admixtures of rowan (*Sorbus aucuparia*) and in lower altitudes also European beech (*Fagus sylvatica*) and European fir (*Abies alba*). The shrub layer is rarely developed, composed of regenerating spruce and rowan. *Calamagrostis villosa, Avenella flexuosa*, and *Vaccinium myrtillus* dominate in the species-poor herb layer. Other typical species are *Homogyne alpina*, *Trientalis europaea*, *Luzula sylvatica*, *Dryopteris dilatata*, *Oxalis acetosella*, and *Galium saxatile* (Moravec et al., 2002). The other spruce dominated forests are edaphically conditioned *Bazzania trilobata*-rich waterlogged spruce forests. Because of the permanently waterlogged soil, Norway spruce dominates almost exclusively in the tree layer. Rowan and birches (*Betula pubescens* agg.) are only rarely admixed. In comparison with the climatically conditioned spruce forests, the herb layer has a lower cover (about 50% or less) in favour of a well-developed moss layer. *V. myrtillus* dominates, while *A. flexuosa*, *V. vitis-idaea*, and *C. villosa* are also often common. *D. dilatata*, *O. acetosella*, *Maianthemum bifolium*, *T. europaea*, *H. alpina*, *Lycopodium annotinum*, and *Soldanella montana* rarely supplement the herb layer (Moravec et al., 2002).

Since the 1990s, a non-intervention regime was established in the area of interest, but also the bark beetle infestation increased. As the bark beetle outbreak spread within the Šumava NP, the core zone without management was reduced in its extent and forestry measures to prevent bark beetle spreading were applied in the rest of the area. Despite the mentioned impacts, the studied area represents one of the most preserved complexes of mountain spruce forests in Central Europe. The most valuable and least directly influenced forests include remnants of original forests to which mainly belong the waterlogged forests. The local mosaic of forests and peat bogs was classified as an Important Plant Area (Palmer and Smart, 2001) and is of high importance within densely populated Central Europe (Čeřovský et al., 2007).

2.2. Research plots

The applied management measures enabled not only long-term observation of the spontaneous development of the disturbed forests after the bark beetle outbreak, but also the contrast with the outbreak followed by clearcutting and replanting. Eighteen permanent research plots (0.04 ha each) were established in the area of interest in 1997 and 1998, at the same time as the bark-beetle attack appeared. Representative parts of the available mature and relatively homogenous spruce stands were chosen based on the advance of the bark beetle spread and the contemporary creation of clearings in part of the area (Jonášová and Prach, 2008).

Research plots of three disturbance types were established: (1) "Dead wood forest" (disturbance type "D", 8 plots) was climatically conditioned mountain spruce forest without forestry intervention and with spontaneous development. The mean crown canopy cover before the outbreak was about 50% and decreased to 37% (the percent total cover of both live and dead canopy) in 1998, 11% in 2002, and nearly 3% in 2012 (live trees on average comprised 0.4% of the canopy cover) as the spruces died off and the needles, branches, bark, and finally the trunks gradually fell. (2) "Clearcut" ("C", 5 plots) was the same type of forest, but the infested spruces were felled, removed, and the slash milled into wood chips and spread on the ground in 1997. In the following years, the clearings were replanted by spruce and rowan. During the last two observations in 2009 and 2012, one plot had to be excluded because of different management than the other clearcut plots